UNIVERSITY OF TECHNOLOGY SYDNEY

Effect of recycled natural water treatment sludge and biochar on the mechanical performance and hydration kinetics of Portland cement composite

by Samuel De Carvalho Gomes

Thesis submitted in fulfilment of the requirements for the degree of **Master of Engineering (Research)**

under the supervision of Prof. John Zhou
Co Supervisor: Doctor Wengui Li

University of Technology Sydney
Faculty of School of Civil and Environmental Engineering

February 2020

CERTIFICATE OF ORIGINAL AUTHORSHIP

I, Samuel De Carvalho Gomes declare that this thesis, is submitted in fulfilment of the requirements for the award of Master of Engineering (Research), in the School of Civil and Environmental Engineering at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

This research is supported by the Australian Government Research Training Program and the Endeavour Postgraduate Scholarship (Masters).

Signature: Production Note: Signature removed prior to publication.

Date : 25/02/2020

ACKNOWLEDGEMENT

First of all, I would like to thank God, heavenly father, for the care and protection at all times during these two years. I would also like to thank my grandfather († Francisco Carvalho) and my grandmother († Rita Gomes) who were two great supporters of my academic life and who passed away last year during my master's degree.

I am sincerely grateful to my supervisor John Zhou, who gave me all the support and knowledge to finish this thesis and also his research group (Romina Ghobadi, Mohammad Boshir and Prof Altaee) who really help me during this journey. I would also like to thank Dr Wengui Li (my co-supervisor) for the significant contribution throughout this project.

I am grateful to my family, especially my father (Manoel Davi) and my mother (Sandra Gomes) for their support and encouragement to continue with my academic life. I also want to thank here all my siblings (Magdiel, Elissama and Daniel) who also encouraged and helped me psychologically in some difficult times here in Australia.

My gratitude extends to my friends and special people here in Australia. Thank you, Daniel Marra, for the support and everything you have done for me on these two years here in Australia. Thank you, Rustam G, for the friendship and academic advice.

Finally, I would like to offer my sincere thanks to the Australian Government through the endeavour scholarships and fellowships program for all the financial support to carry out this research project.

LIST OF PUBLICATIONS

- **Gomes, S. D. C.,** Zhou, J. L., Li, W., & Long, G. 2019, Progress in manufacture and properties of construction materials incorporating water treatment sludge: A review. Resources, Conservation and Recycling, 145, 148-159.

- **Gomes, S. D. C.,** Zhou, J. L., Li, W., & Qu, F. (2020). Recycling of raw water treatment sludge in cementitious composites: effects on heat evolution, compressive strength and microstructure. Resources, Conservation and Recycling, 161, 104970.

Table of Contents

LIST OF FIGURES

LIST OF TABLES

Abstract

Water treatment sludge (WTS) management is a growing global problem for water treatment plants (WTPs) and governments. This research examines the application of natural WTS and thermally modified sludge (WTS-biochar) as a construction materials ingredient by converting a waste by-product to a value-added product. Important aspects such as the physicochemical interaction of the sludge/biochar with the Portland cement, the hydration kinetics of the cement paste and the mechanical behaviour of the composite were carefully studied. The results show that for 1-2% of WTS addition, the compressive strength and heat evolution of the cement paste was well maintained being close to the reference specimen after 28 days of curing. However, for sludge addition above 5%, a delay in the hydration reaction was observed, together with about 25% reduction in compressive strength at 28 days of curing. The mineralogical and thermal analysis showed decreasing portlandite content and increasing calcite in the WTS-amended composites. Scanning electron microscope analysis demonstrated that the addition of sludge induced more porous and weak surface structures compared to the reference specimen. The thermally modified WTS (biochar) show an improvement in material kinetics and mechanical properties. The mineralogical, thermal and microscopic analysis shows several pieces of evidence of pozzolanic activity of the biochar. The samples with 2% and 5% WTS-biochar showed higher heat release than the reference material. Specimens with 1%, 2% and 5% WTS-biochar showed a slightly higher compressive strength at 28 days compared to the reference material. As a result of all these findings, this project has shown strong indications that WTS can be promoted as a sustainable and alternative resource for construction materials with less environmental impacts as well as economic savings.

Keywords: Water treatment sludge; Construction materials; Biochar; Cement mortar; Pyrolysis